REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	July 24, 1996	Final 3/01/93 - 02/28/96

4. TITLE AND SUBTITLE
Semantic Theories an Automated Tools for Real-Time and Probilistic Concurrent Systems

5. FUNDING NUMBERS
F49620-93-1-0169

6. AUTHOR(S)
Professor Amy E. Zwarico

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
The Johns Hopkins University
3400 N. Charles Street
Baltimore, MD 21218

8. PERFORMING ORGANIZATION REPORT NUMBER
AFOSR-TR
96-0419

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
AFOSR/NM
110 Duncan Ave, Suite B115
Bolling AFB DC 20332

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

19960813 168

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION AVAILABILITY STATEMENT
Approved for public release:
Distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The results fall into two primary categories: real-time process algebras and type theories for object oriented programs The process algebra results include a richer semantic framework for expressing real time processes, the development of an algebra for expressing both preemptive and nonpreemptive processes, axiomatizations of the algebra, implementations of these axiomatizations, and equivalence for Pict, a concurrent object-oriented programming language based on the π-calculus. The OO results include the development of constraint-based type systems (including inference algorithms) for object-oriented languages.

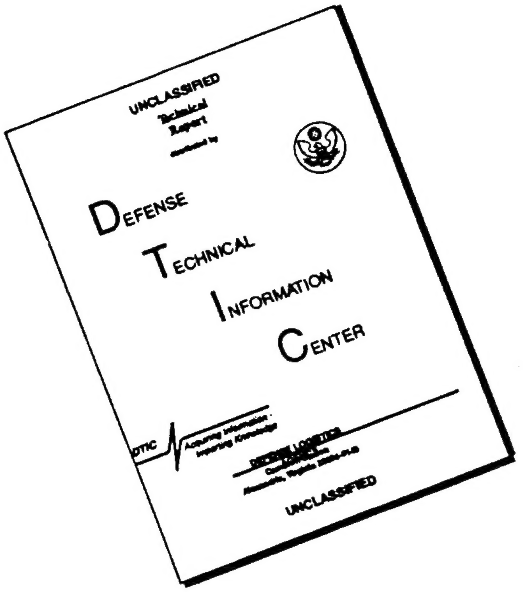
14. SUBJECT TERMS

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR

DISCLAIMER NOTICE



UNCLASSIFIED
Technical
Report
distributed by

DEFENSE
TECHNICAL
INFORMATION
CENTER

DTIC
Acquiring Information -
Imparting Knowledge

DEFENSE LOGISTICS
AGENCY
Cameron Station
Alexandria, Virginia 22304-6145

UNCLASSIFIED

THIS DOCUMENT IS BEST QUALITY AVAILABLE. THE COPY FURNISHED TO DTIC CONTAINED A SIGNIFICANT NUMBER OF PAGES WHICH DO NOT REPRODUCE LEGIBLY.

Final Progress Report:
Semantic Theories and Automated Tools for Real-Time and Probabilistic Concurrent Systems

1 Results

The results fall into two primary categories: real-time process algebras and type theories for object oriented programs. The process algebra results include a richer semantic framework for expressing real-time processes, the development of an algebra for expressing both pre-emptive and nonpre-emptive processes, axiomatizations of the algebras, implementations of these axiomatizations, and equivalences for Pict, a concurrent object-oriented programming language based on the π-calculus. The OO results incluce the development of constraint-based type systems (including inference algorithms) for object-oriented languages.

- We extended the class of nonpre-emptive processes first developed in [?]; revised the alternative characterization of nonpre-emptive processes; defined both real-time and nonpre-emptive algebras; and axiomatized the timed preorders. The extension of the class of nonpre-emptive processes allows us to represent more nondeterministic processes, thus increasing the expressivity of the formalism. The real-time algebra, in conjunction with the testing preorders, allows us to express general timing constraints such as upper and lower bounds. The nonpre-emptive algebra is useful because it can only be used to express nonpre-emptive processes. Furthermore, the nonpre-emptive preorders are precongruences for all operators of the algebra. We have used results from [?, ?] to develop the axiomatizations for both the general real-time algebra and the nonpre-emptive algebra.

- We currently have a Standard ML implementation of BDD's for the real-time algebras developed. We are using Emerson's quantitative mu-calculus [?]. to specify formulas which are to be checked in the model.

- We are developing eqvivalences for Pict, a concurrent object-oriented programming language based on the π-calculus. Pict consists of a core language in which higher-level language can be defined. Proving equivalence of Pict programs consists in first developing an equivalence for core Pict, developing translation rules that map high-level constructs into low level ones, and proving that the translation rules preserve program equivalence. Thus if two high-level programs are equivalent then so are their core-level translations.

- The development of rich type systems for object-oriented programming languages. Our main area of interest is constraint-based type inference for object-oriented languages.

  Type inference, the idea of automatically inferring type information from untyped programs, is originally due to Hindley and Milner. The type inference for object-oriented languages is more difficult than for traditional sequential programs because even simple object-oriented programs are more "advanced" type-theoretically. Object types can be self-referential so some form of recursive type is also needed. This can be captured using a form of operator polymorphism or F-bounded polymorphism.

  We hav defined a polymorphic, constraint-based type inference algorithm for an object-oriented language, I-Loop. This language incorporates standard notions of class, multiple inheritance, object creation, message send, mutable instance variables, and hiding of instance variables. Thus, there is enough of a core that we are reasonably confident the ideas will scale up to an implemented language. We infer a generalized form of type, recursively constrained (rc) types of the form $\tau\ C$, with "reading "where." C is a set of type constraints of the form $\tau <:$ \$tau′ possibly containing free type variables. These constraints may be recursive in that a variable t could occur free in both τ and τ'. This form of type is not standard, and generalizes existing notions. The rc types have the advantage of being very expressive, but the disadvantage of being more difficult to read. The recursive constraints generalise recursive types and the rc-polymorphism generalizes F-bounded polymorphism. The constrained type inference approach to objects allows the inference of very detailed rc types. Far more precise than any type a programmer is likely to come up with. And, this will in turn give the programmer a degree of flexibility well beyond what is provided by current typed object-oriented langauges.

2 Papers

- Elizabeth Leonard and Amy Zwarlco, "an Algebraic Framework for Developing and Maintaining Real-Time Systems," AMAST '95, Lecture Notes in Computer Science, vol. 936, Springer Verlag.
- Kim B. Bruce, Luca Cardelli, Giuseppe Castagna, Scott F. Smith, Jonathan Eifrig, Valery Trifonov, Tiejun Wang, Gary T. Leavens, and Benjamin Pierce. On Binary Methods. Submitted for publication. Department of Computer Science, Iowa State University, TR95-08¡/A¿: May 1995.
- J. Eifrig, S. Smith, V. Trifonov, "Sound Polymorphic Type Inference for Objects," OOPSLA 1995.
- J. Eifrig, S. Smith, V. Trifonov, "Type Inference for Recursively Constrained Types and its Application to OOP", Mathematical Foundations of Programming Semantics 1995 (Elsevier Electronic Notes in Theoretical Computer Science, volume 1).
- J. Eifrig, S. Smith, V. Trifonov, A. Zwarico, "Application of OOP Type Theory: State, Decidability, Integration", OOPSLA 1994.
- J. Eifrig, S. Smith, V. Trifonov, A. Zwarico. "An Interpretation of Typed OOP in a Language with State", Lisp and Symbolic Computation, 8 (4), 1995.
- J. Eifrig, S. Smith, V. Trifonov, A. Zwarico, "A Simple Interpretation of OOP in a Language with State", Workshop on State in Programming Languages, 1993.

3 Supported Students

Elizabeth Leonard, Jonathan Eifrig, Valery Trifonov